FLAMMABILITY OF PAINTED GYPSUM WALLBOARD SUBJECTED TO FIRE HEAT FLUXES

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ABSTRACT

The flammability of painted gypsum wallboard (GWB) exposed to fire heat fluxes is investigated using the Cone Calorimeter[1]. 16-mm (5/8-in.) thick Type-X GWB samples, painted with 2, 4, 6 or 8 coats of latex interior paint over a single coat of latex primer, are subjected to incident heat fluxes ranging from 25 to 75 kW/m^2 for periods ranging from 5 to 15 minutes. A flame spread model developed by Quintiere and coworkers[2,3,4] and previously applied by Mowrer and Williamson[5] to thin finishes on GWB substrates is used to evaluate the potential for flame spread on painted GWB. The concept of a critical heat flux for flame spread is developed for thin combustible.

INTRODUCTION

Painted GWB is the most widely used interior finish in the United States and perhaps throughout the world. Consisting of a core of gypsum (calcium sulfate dihydrate) sandwiched between two paper facers, GWB is available in a range of standard sizes and thicknesses. Because of its ease of installation, the use of GWB has largely replaced the use of traditional lath and plaster in both residential and commercial applications.

In many fire scenarios involving painted GWB finishes, the exposed painted surface and paper facer have been observed to burn out locally when subjected to fire heat fluxes. Such damage patterns have been used by fire investigators to draw conclusions regarding the development of a fire. In other scenarios, the painted surface and paper facer have been observed to propagate a fire. The objective of this study has been to evaluate the potential for flame spread on painted GWB and to determine the exposure conditions under which flame propagation will occur. Cone calorimetry has been used in conjunction with a flame spread model developed by Quintiere and coworkers [2,3,4] to perform this evaluation. A sensitivity analysis is conducted to determine the key parameters controlling the potential for flame spread on painted GWB surfaces. Based on this analysis, a relationship for evaluating the critical heat flux for upward flame spread is derived.

CONE CALORIMETER TESTS

Painted GWB samples were subjected to constant incident heat fluxes of 25, 50 and 75 kW/m^2 for periods ranging from 5 to 15 minutes in the Cone Calorimeter. Two, four, six and eight coats of latex interior paint were applied over a single coat of latex primer to the exposed paper surface of 16-mm (5/8-in.) thick Type-X GWB. Unpainted GWB samples were evaluated for comparison. Typically, three replicate tests were performed for each combination. Average test results for each combination are summarized in Table 1 and representative heat release rate curves are shown in Figures 1(a) and 1(b).

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FLAME SPREAD MODEL

The model used to evaluate the potential for flame spread on painted GWB is undergoing continued development by Quintiere and coworkers[2,3,4]. This flame spread model produces a "flammability parameter" defined as:

$$b = k_f \dot{Q}'' - (t_{ig}/t_b) - 1 \tag{1}$$

where k_f - Characteristic flame length coefficient (~0.01 m^2/kW)

$\dot{Q}''$ - Characteristic heat release rate per unit area (kW/m^2)

t_{ig} - Characteristic ignition time (s)

t_b - Characteristic burning duration (s) [$Q''/\dot{Q}''$]

Q'' - Characteristic heat release per unit area (kJ/m^2)

According to the Quintiere model, acceleratory flame spread is indicated when the value of the flammability parameter is positive, while decay to extinction is expected if the flammability parameter is negative.

Evaluation of the flammability parameter requires evaluation of the respective parameters used to calculate it. Mowrer and Williamson[5] describe a technique for using Cone Calorimeter data directly to evaluate these characteristic parameters and the associated flammability parameter for thin materials adhered to noncombustible substrates. These materials tend to exhibit distinct peaks in their heat release rate histories. For a given incident heat flux, the ignition time (t_{ig}), the peak unit heat release rate ($\dot{Q}''$) and the unit total heat release (Q'') are measured and substituted directly into Equation 1. This technique was used to calculate the flammability parameter for the different combinations of incident heat flux and coats of paint; results are shown in Table 1. Exemplar heat release rate curves for the different coats of paint are shown in Figures 1(a-b).

RESULTS

The painted GWB samples did not ignite at an exposure heat flux of 25 kW/m^2. When subjected to an imposed heat flux of 50 kW/m^2, ignition times for the painted samples ranged from 41 to 43 seconds, peak unit heat release rates ranged from 211 to 240 kW/m^2 and burning durations were 11 seconds. At this heat flux, the flammability parameter calculated by Equation 1 was always negative, with values in the range of -2.6 to -2.8. These values strongly suggest that acceleratory flame spread is not likely to occur at an incident heat flux of 50 kW/m^2. In comparison, at an imposed heat flux of 50 kW/m^2, the unpainted sample ignited in 37 seconds, burned out in 14 seconds and had a peak heat release rate of 111 kW/m^2, approximately one-half the value of the painted samples. The flammability parameter for the unpainted sample has a value of -2.6.

At an imposed heat flux of 75 kW/m^2, ignition times for the painted samples decreased to 15 to 17 seconds, peak unit heat release rates ranged from 206 to 215 kW/m^2 and burning durations from 14 to 16 seconds. At this heat flux, the flammability parameter ranged of -0.06 to +0.03; these values suggest that painted GWB is on the threshold of acceleratory flame spread at an incident heat flux of 75 kW/m^2. At this heat flux, the unpainted sample ignited in 14 seconds, burned out in 11 seconds and achieved a peak heat release rate of 134 kW/m^2. For these values, the flammability parameter evaluates to -0.9, suggesting acceleratory spread is not likely.

The variation of the flammability parameter with imposed heat flux is shown graphically in Figure 2. These results suggest that flame spread should not occur on painted GWB until an incident heat flux of approximately 75 kW/m^2 is achieved, irrespective of the number of coats of paint.

SENSITIVITY

The potential for flame spread on thin combustible surfaces adhered to noncombustible substrates can be viewed as a race between the rate of ignition of new material and the burnout rate of material already ignited. The sensitivity of the flammability parameter (b) is considered in terms of the ratio between the ignition time (t_{ig}) and the burning duration (t_b). The ignition time of a thermally thick material subjected to a constant heat flux is generally taken to be:

$$t_{ig} = \frac{\pi}{4} \frac{k\rho c\left(T_{ig} - T_0\right)^2}{\dot{q}''^{\,2}_{net}} \tag{2}$$

The burning duration can be represented as the ratio between the fuel mass per unit area and the characteristic mass loss rate per unit area:

$$t_b = \frac{m''}{\dot{m}''} = \frac{\rho\delta_b}{\dot{q}''_{net}/L} = \frac{\rho\delta_b L}{\dot{q}''_{net}} \tag{3}$$

Assuming that the net heat flux back to the burning surface is the same as the net heat flux to an adjacent element, the criterion that the ignition time for the next element must be less than the burning duration for the current element, $t_{ig} < t_b$, can be established. The criterion is determined by comparing Equations 2 and 3:

$$\frac{\pi}{4} \frac{k\rho c_p\left(T_{ig} - T_0\right)^2}{\dot{q}''^{\,2}_{net}} < \frac{\rho\delta_b L}{\dot{q}''_{net}} \tag{4}$$

Rearranging and solving for the net heat flux results in the critical heat flux necessary for flame spread to occur.

$$\dot{q}''_{critical} > \frac{\pi}{4} \frac{k\rho c_p\left(T_{ig} - T_0\right)^2}{\rho\delta_b L} \tag{5}$$

The implications of this analysis are that, for thin materials, there will be critical heat flux below which flame spread will not occur, and above which flame spread may occur, depending on relative ignition times and burning durations. The higher the critical heat flux for flame spread for a material, the less likely it would contribute to acceleratory flame spread.

The critical heat flux for flame spread is determined experimentally by determining when the ratio between the burning duration and the ignition time exceeds unity:

$$\frac{t_b}{t_{ig}} = \left(\frac{\rho\delta_b L}{\frac{\pi}{4} k\rho c_p\left(T_{ig} - T_0\right)^2} \right) \dot{q}''_{net} > 1 \tag{6}$$

The ratio between the burning duration and the ignition time can be determined for a range of imposed heat fluxes in the Cone Calorimeter. According to Equation 6, this ratio should vary linearly with the imposed heat flux, with the slope of the line related to the indicated material properties. Figure 3 demonstrates the variation of the ratio given in Equation 6 as a function of the imposed heat flux for the different coats of paint. Data at a third heat flux would be useful to evaluate the indicated linearity of this relationship. Such data are currently being obtained.

The relationship shown in Figure 3 follows a trend similar to the b number shown in Figure 2. Both the b number analysis and the critical heat flux for flame spread analysis indicate that the threshold heat flux for flame spread on painted GWB is in the vicinity of 75 kW/m^2. At lower heat fluxes, localized burnout would be indicated.

As demonstrated by Equation 6, the critical heat flux for flame spread is expected to increase with increasing fuel thickness (δ_b) and decrease with increasing thermal inertia ($k\rho c$) of a material. As a result, low-density materials may be expected of exhibit lower critical heat fluxes than high-density products. While not considered explicitly here, the effect of preheating could be considered as well in terms of the initial surface temperature of the material. As the initial surface temperature (T_o) of a material increases, the critical heat flux would be expected to decrease, as indicated in Equation 6.

SUMMARY AND CONCLUSIONS

This investigation suggests that flame spread is not likely on painted gypsum wallboard at incident heat fluxes of 50 kW/m^2 or less, while flame spread may occur at heat fluxes of 75 kW/m^2 or higher. The effects of preheating of GWB, as might occur in a room fire, have not been investigated, but these effects might be considered through appropriate adjustments in the ignition time used in Equation 2. This will be investigated in the future.

This analysis is based on an assumption of constant and uniform heat flux in both the pyrolysis and flame front regions; it has not addressed potential changes in incident heat flux in the flame region, above the pyrolysis zone. Tu and Quintiere[6] suggest that wall flames typically generate heat fluxes of approximately 30 kW/m^2 in this region. Consequently, it can be argued that the characteristic ignition time term in Equation 2 should be taken as the ignition time associated with a heat flux of approximately 30 kW/m^2, while the characteristic unit heat release rate and burning duration should be associated with the incident heat flux from an exposure fire. Mowrer and Williamson[5] found that this approach seemed to yield the most consistent flammability parameter results for textile wall coverings. In general, this approach would yield a lower value for the flammability parameter and a consequent reduction in the indicated potential for flame spread. It can also explain why some thin fuels subjected to incident heat fluxes above the critical heat flux for upward flame spread might still decay to extinction rather than spread a fire.

Based on the data obtained to date, it is not possible to distinguish a difference in flame spread propensity based on the number of coats of paint. The incident heat flux has much more of an influence on the potential for flame spread than does the number of latex paint coats, at least over the number of coats investigated. Work is continuing to investigate the effects of additional coats of paint on the propensity for flame spread on GWB. Future work will also consider oil-based paint as well as other surface finishes, such as wallpaper.

ACKNOWLEDGEMENTS

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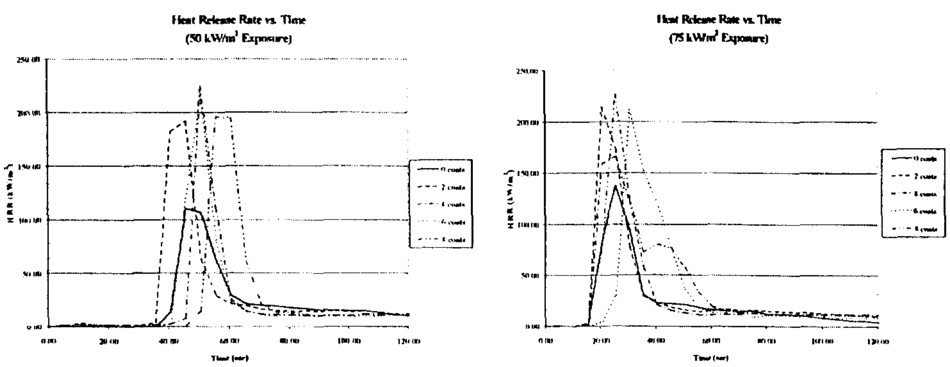
Table 1. Cone calorimeter results and calculated flame spread parameters.

Heat Flux (kW/m^2)	Coats of Paint	t_{ig} (sec)	$\dot{Q}''_{peak}$ (kW/m^2)	Q'' (kJ/m^2)	t_b (sec)	b (-)	Flame Spread Indicated?
25	0	NI	N/A	N/A	N/A	N/A	NI
25	2	NI	N/A	N/A	N/A	N/A	NI
25	4	NI	N/A	N/A	N/A	N/A	NI
25	6	NI	N/A	N/A	N/A	N/A	NI
25	8	NI	N/A	N/A	N/A	N/A	NI
50	0	36.73	111.39	1561.38	14.07	-2.55	NO
50	2	40.74	210.85	2284.04	10.94	-2.65	NO
50	4	41.59	223.99	2359.08	10.68	-2.69	NO
50	6	44.29	240.30	2651.49	11.07	-2.63	NO
50	8	43.10	215.18	2366.07	11.06	-2.75	NO
75	0	13.98	134.35	1527.44	11.36	-0.91	NO
75	2	15.20	206.12	2773.34	13.51	-0.06	NO
75	4	15.73	209.69	2948.98	14.24	-0.02	NO
75	6	17.10	215.14	3318.20	15.79	0.03	Yes
75	8	8.59	214.29	3378.38	15.78	0.60	Yes

NI = No Ignition



Figures 1(a) and 1(b). Cone calorimeter results for painted gypsum wallboard

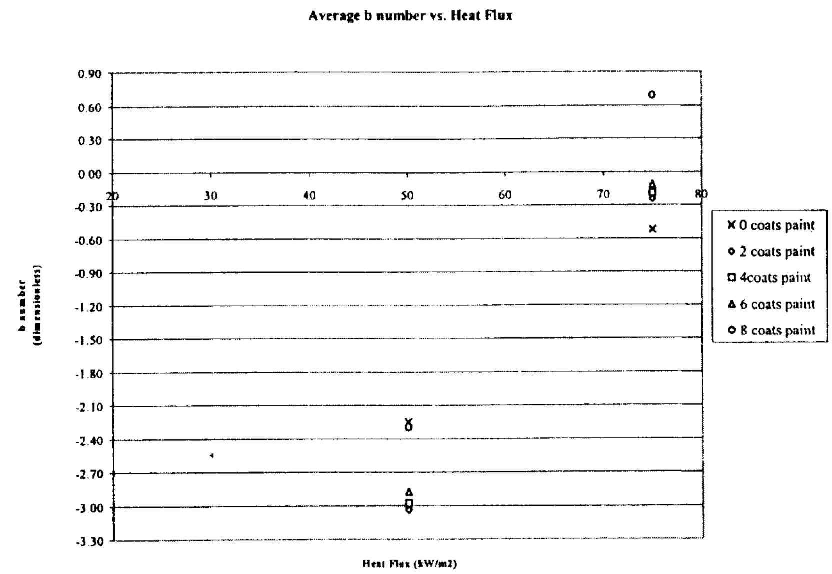


Figure 2. Flammability Parameter as a function of external heat flux.

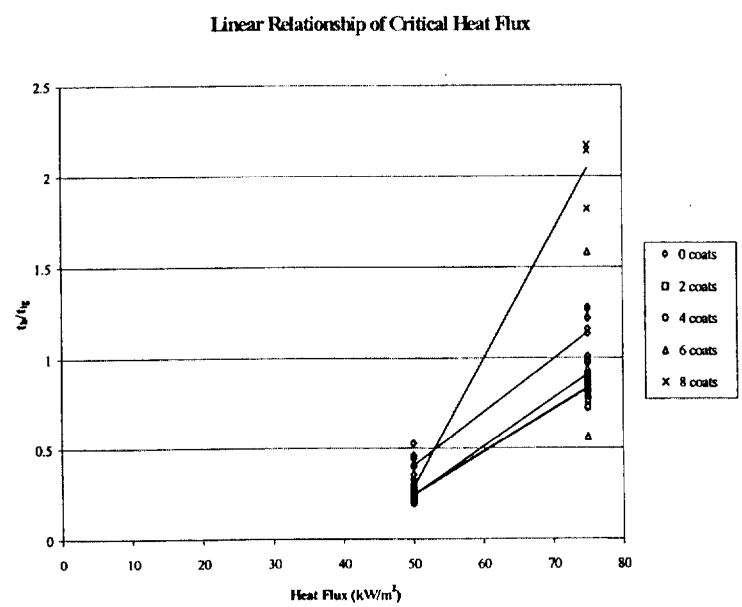


Figure 3. Linear relationship of the critical heat flux for flame spread.